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CUMULATIVE EFFECTS OF CHANNEL AND EBB SHOAL DREDGING ON INLET EVOLUTION IN SOUTHWEST FLORIDA, USA

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This paper describes analysis and numerical modeling of tidal inlets in southwest Florida, where coverage of large temporal and spatial scales is necessary. A methodology is introduced for examining the response of complex inlet systems to dredging, including modeling of regional hydrodynamics, wave-current interaction, sediment transport, and application of the Inlet Reservoir Model. A case study for Longboat Pass, Florida, demonstrates this methodology. Longboat Pass is one of several tidal connections between the Gulf of Mexico and the Sarasota Bay system. The study covers evolution of Longboat Pass from 1880 to present. The analysis begins with natural conditions that existed before dredging or inlet modifications and investigates how inlet evolution is influenced by navigation improvements and mining of the ebb shoal for beach nourishment.

INTRODUCTION

Barrier Islands separated by tidal inlets are representative of the majority of the gulf coast of southwest Florida, USA. Along several reaches of this coast where multiple inlets share the tidal prism of large bays, analysis of regional spatial scales is needed. On the other hand, the long timeframe of inlet evolution and morphology response to natural and anthropogenic changes require evaluation of morphologic change at long time scales. The long timeframe of inlet evolution and morphology response to dredging may limit practical application of advanced coastal area models to investigation of short-term (order of seasons to a few years) morphology change. The response timeframe is a key factor because, in dealing with large sand shoals, adjustment in bypassing and morphology may require years or even decades before all changes become manifest. Dabees and Kraus (2004, 2005) presented a general methodology that combines technologies analyzing data and numerical simulations done at short and long time scales for examining the response of complex inlet systems to sediment mining at two inlets in southwest Florida. The methodology includes application of the Inlet Reservoir Model (IRM) (Kraus 2000a, 2000b) that simulates long-term evolution of inlet shoals.

Methodology

The methodology is based on numerical modeling and data analysis for various spatial and time scales to evaluate an inlet evolution, existing condition, and alternatives. The analysis includes observed inlet evolution, and numerical

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modeling of regional hydrodynamics, waves, and sediment transport at key times to simulate main stages of the observed inlet system evolution. Process-based modeling results serve as input to the IRM to quantify volumetric change and bypassing rates between the different morphologic features that comprise the inlet shoal system. This approach provides understanding of regional processes, localized processes at subject inlets including long-term inlet evolution, and morphologic responses to human-induced alterations to natural systems where that has occurred.

LONGBOAT PASS CASE STUDY

Longboat Pass is a tidal inlet in southwest Florida connecting the north part of Big Sarasota Bay to the Gulf of Mexico. The inlet is part of a large multi-inlet bay system, made up of the large and shallow bay areas of Sarasota Bay which are connected to the Gulf of Mexico by several tidal inlets. Longboat Pass is located between Anna Maria Island to the north and Longboat Key south. Figure 1 shows the location of longboat Pass.

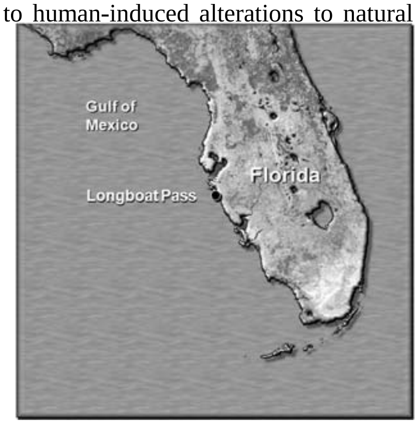

Fig. 1. Longboat Pass Location

The Longboat Pass study (H&M 2008) compiled recent and historic surveys, aerial photographs, and other data to quantify morphologic change throughout the inlet's evolution and to provide input for numerical models. The complex nature of the inlet required analysis of inlet evolution over a long time interval from the 1880s to present. The regional coverage including large time scale modeling were necessary to quantify changes in tidal prism due to natural and anthropogenic changes. Major anthropogenic changes during the past century cover general infrastructure and bayside development, navigation improvements, and beach restoration projects. The main modeling stages spanned three temporal conditions, the 1880s, the 1950s, and present conditions. The 1880s represented natural conditions before any development in the region, the 1950s represented the conditions immediately prior the major navigation improvements such as jetty constructions and dredging of navigation channels, and present conditions represented the hydrodynamic and morphologic response to the various natural and anthropogenic change over the past half century. Compilation of historical data was essential for verification of the accuracy of model computations to improve confidence in computed results.

Numerical modeling

Figure 2 shows the regional and local model coverage limits for the Longboat Pass study. The regional hydrodynamic model served to establish boundary conditions for the Longboat Pass detailed or local model for the three various temporal conditions describing the varying stages of the system. The local modeling of waves, currents, sediment transport and their interaction provided process-based estimates of sediment pathways at various morphologic stages. Finally, the compiled data and process modeling results served as input for the inlet evolution modeling.

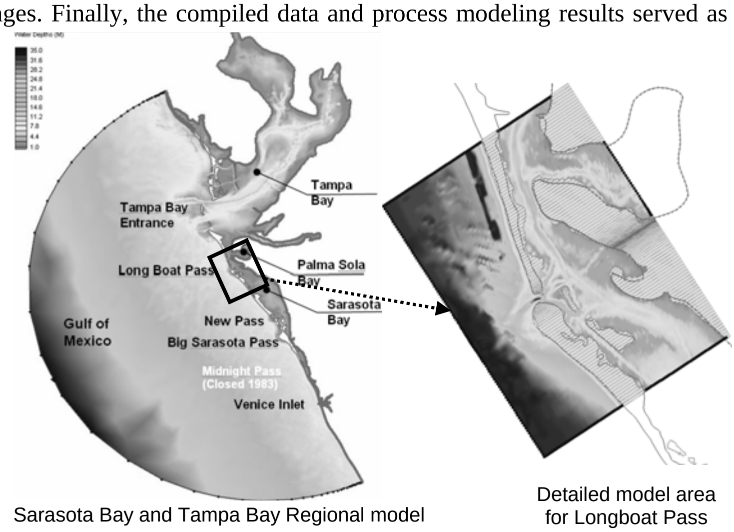

Fig. 2. Longboat Pass modeling coverage

The regional model spanned more than 100 km alongshore the Gulf of Mexico coastline, representing several interconnected bays and barrier islands and the 10 inlets that connect the bays to the Gulf of Mexico. The regional hydrodynamics were simulated with the Advanced Circulation (ADCIRC) model (Luettich, et al. 1991). The local models for Longboat Pass were the Coastal Modeling System – CMS (Buttolph et al. 2006) for hydrodynamic and sediment transport, and the IRM for long-term morphology evolution.

Inlet evolution analysis

Natural Inlet evolution 1880s to 1950s. The earliest bathymetric data available are the 1876 and 1883 U.S. Coast and Geodetic Surveys. At that time Longboat Pass was located approximately 500 m south of its present location, as illustrated in Figure 3 (the federal channel authorized in 1977 is superimposed on this figure for illustrative reference). The survey of 1876 shows a single inlet and a large ebb shoal with a southwest orientation of the gulf channel. The 1883

survey of the bay indicates another inlet opening to the north creating a dual inlet system. Figure 4 shows selected aerial photos of the conditions in the vicinity of Longboat Pass from 1940 to 1969. The 1940s inlet configuration consisted of a two-channel sys Because the original inlet was more restrictive, the newer inlet became more dominant as it gradually captured a larger share of the tidal prism. This dual inlet situation continued until the south inlet closed in the 1950s. Onshore move-ment of the ebb shoal at the closed inlet provided a large volume of material to the down-drift beach (Longboat Key) and formation of the active ebb shoal to the north. Formation of the new ebb shoal caused significant erosion on the north side of inlet, along the south end of Anna Maria Island. Comparisons of 1880s and 1955 surveys indicate over 2 million cubic meters eroded from the beach and nearshore shoals along Anna Maria Island to form the Longboat Pass shoal system. Closure of the old inlet in the early 1950s and the onshore migration of the ebb shoal resulted in formation and growth of a sand spit at the north end of Longboat Key. The seaward advance of the shoreline at south side of the inlet coupled with the shoreline retreat on the north side created a shoreline offset between the two sides of the inlet.

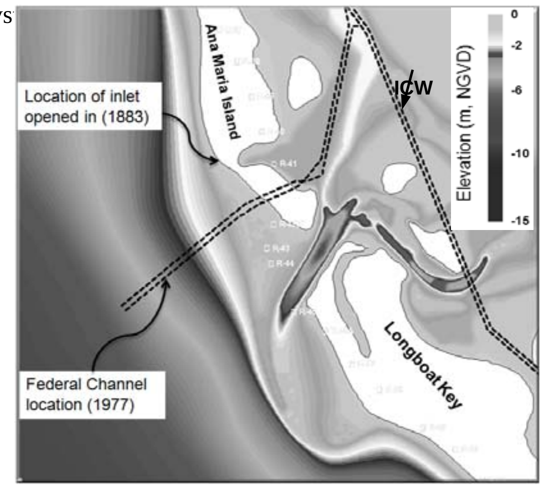

Fig. 3. Longboat Pass (1876 survey)

The wave and current modeling for 1955 conditions were analyzed to explain the inlet dynamics prior to navigation improvements at the inlet. The model results indicated that during flood tide the ebb shoal provided a pathway for littoral transport to bypass the inlet, and it sheltered the shoreline from direct wave action. The ebb shoal therefore provided a level of natural beach erosion control and reduced sediment transport into the inlet during flood tide. During ebb flow, in the 1950s, the ebb shoal provided the bypassing bars and channel margin shoals on both sides which extended the ebb jet seaward. The ebb currents created a near-symmetric ebb shoal by allowing sediment carried by the ebb jet to be deposited on both the north side as well as south side of the inlet.

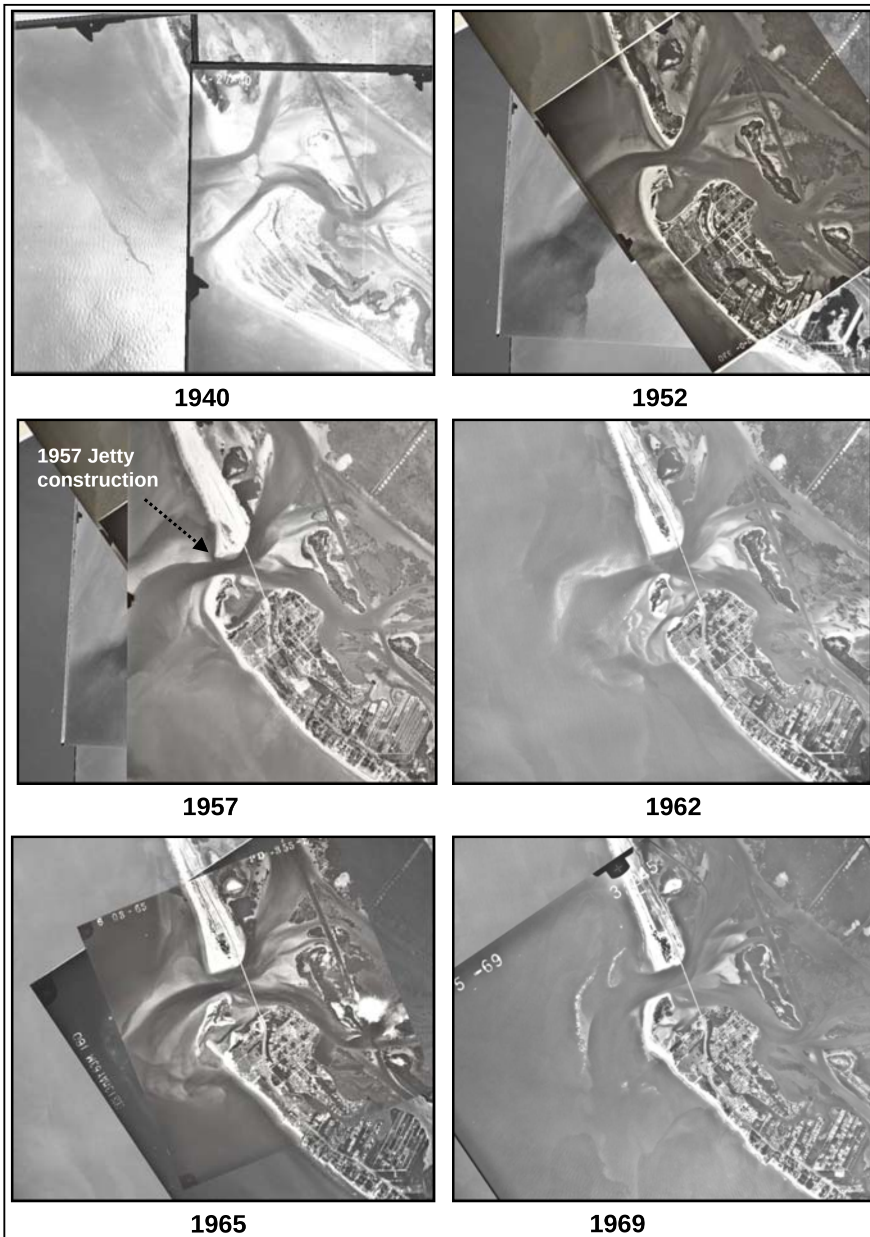

Fig. 4. Longboat Pass (1942 to1969 aerial photographs)

Inlet navigation improvements. Major development in the region during the late 1950s included construction of the jetty on the north side of the inlet to support the landing for the bridge across the inlet built in 1957. The long jetty interrupted sediment movement toward the inlet and likely reduced bypassing to the downdrift side. This resulted in increased erosion along the downdrift beach on Longboat Key and may have caused the breaching of the sand spit as shown on the 1962 aerial photograph in Figure 4. Bypassing appears to have been reestablished a few years later as the jetty impoundment approached capacity and the spit reattached to Longboat Key as shown in the 1969 photograph. The jetty impoundment over the years helped advance the shoreline on the north side of the inlet and pushed the ebb jet further offshore.

The regional model results indicated a 20% increase in tidal prism through Longboat Pass between 1950s and present conditions. This increase occurred due to expansion of the northern limit of the inlet's effective bay to include portions of the bay system north of Sarasota Bay. Changes that contributed to this include construction of the Longboat Pass north jetty in 1957, the improvement of the Intracoastal Waterway (ICW), and the dredging of the federal inlet navigation channel in 1977. The dredging of the navigation channels and jetty construction improved the hydraulic efficiency of Longboat Pass, increasing the tidal prism through the inlet. As a result, the ebb shoal grew in volume and extended further offshore. The growth of the ebb shoal can be observed in the aerial photographs and the survey data of the 1980s and 1990s (H&M 2008).

Longboat Pass federal navigation channel was authorized and first dredged in 1977 after Corps of Engineers Detailed Project Report on Longboat Pass was completed in 1975. Including the initial dredging of that project in 1977, the inlet has been dredged five times as a federal project (Taylor 2002).

1993 Mining of the Ebb Shoal. In addition to maintenance dredging of the navigation channel, the seaward portion of the Longboat Pass ebb shoal was dredged in 1993 to remove approximately 1.5 million cubic meters of sand for beach restoration on Longboat Key. The dredging that took place in 1993 significantly altered the geometry and volume of sand in the ebb shoal. Figure 5 shows the pre and post dredging bathymetry for Longboat Pass.

Wave, flow, and sediment transport were simulated for pre and post 1993 dredging to evaluate the changes caused by the dredging. Wave and current interactions for the pre and post dredging conditions were simulated with the CMS to quantify the change in sediment exchange pattern between features. The model results indicate the consequence of the dredging on changing the current circulation across the ebb shoal. Under the post dredging conditions, the seaward extent of the ebb jet current became much shorter due to the widening of the cross section area near the dredging location.

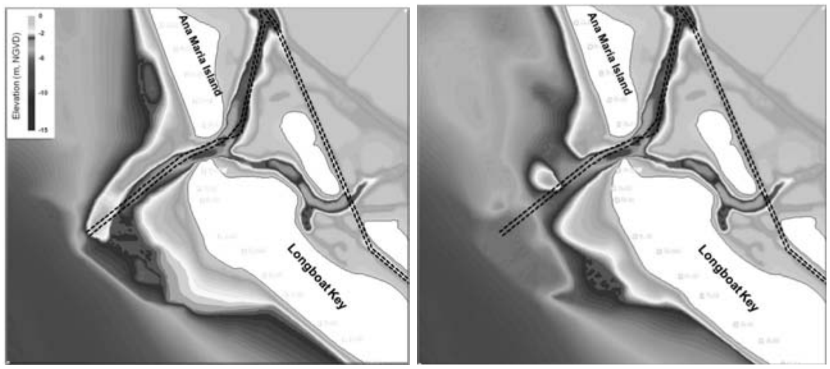

Fig. 5. Longboat Pass bathymetry pre and post ebb shoal mining)

The CMS was also run to simulate conditions 5 and 14 years post dredging to identify the change in inlet dynamics as it evolved after mining of the ebb shoal. The process modeling of the pre- and post-dredging conditions identified the change in circulation patterns as the ebb jet and morphologic features migrate further south. The model also indicated the post-dredging exposure of the sand spit to higher wave energy and erosion of the sand spit at the south side of the inlet. This resulted in the ebb channel and shoal system migrating landward. The process modeling results were input to the IRM to quantify the evolution of the morphologic features of Longboat Pass.

Inlet Reservoir Model for Longboat Pass

The IRM calculates sediment transport rates and volume change of identified morphologic features and bypassing rates for an inlet. It was applied to the Longboat Pass tidal shoal complex for the various morphologic stages. The first step is to identify sediment pathways across the ebb shoal and distinct morphologic features that form the shoal complex. In a typical wave-dominated inlet, there would be three distinct ocean-side features: an ebb shoal, bypassing bar, and an attachment bar. The concept of the IRM is based on the assumption that each feature has a maximum (equilibrium) sand-retention capacity that cannot be exceeded. Once a feature has reached capacity, all additional sediment transport to that feature will bypass to the next feature(s), and so forth until sediment arrives at the downdrift side of the inlet, or is deposited in another location such as the channel or flood shoal. If a morphologic feature is partially full, it still provides partial bypassing. The IRM calculates growth of the shoals as a function of the littoral drift and equilibrium volumes of the shoals, and it accounts for the naturally long timescales of large morphologic features and time delays in exchange of material among the features. Further information on the IRM can be found in Kraus (2000a, 2000b, 2002) and in Dabees and Kraus (2004, 2005).

IRM Setup. The Longboat Pass ebb-shoal system is more complex than that of a typical inlet. The complexity is the result of changes in tidal prism over time and the resulting changes in the equilibrium volume for the ebb shoal. IRM applications are typically based on a constant equilibrium volume of the morphologic features. In the present study, the modeling was divided into three stages corresponding to different, but constant, tidal prisms respectively. The first stage, 1880-1957, is the period from the opening of the inlet until the construction of the north jetty, which increased the tidal prism by approximately 20% of the prism before the jetty and ICW construction. The second stage continues from 1957 to 1993, when the 1993 mining of the ebb shoal caused the shoal to migrate landward and its equilibrium size decrease due to erosion and southward migration of the inlet. The third stage, 1993 to 2040, covers the inlet evolution post the 1993 mining of the ebb shoal to present conditions plus future projection.

The CMS wave, tidal hydrodynamic, and sediment transport modeling results, coupled with interpretation of the bathymetric data, were evaluated to define sediment pathways for each stage of Longboat Pass evolution. Based on the CMS modeling and documented elevation change, the sediment pathways and morphological features were represented for each of the three temporal stages. Sediment pathways for the both north and south transport direction were included in the model to account for all sediment inputs to the inlet systen

Sediment transport inputs for bo directions were calculated using the years (1980-1999) of wave data fro WIS Station 277. Potential averag minimum, and maximum transpo rates were computed using the 20 ye record. The bathymetric da considered together with the IR results defined the distir morphologic features in the syster For the three temporal stages of t inlet evolution, the following featur have been present: an ebb shoal, flood shoal, bypassing bars north a south of the inlet, and a sand spit on the south side of the inlet. The ebb shoal was divided in two features: ebb shoal north and ebb shoal south on either side of the channel centerline. A jetty impoundment feature was added to account for the jetty impoundment and its control on down-drift bypassing rates in 1957. Figure 6 shows an illustration of the morphologic features and sediment pathways for Longboat Pass for the period 1957 to 1993.

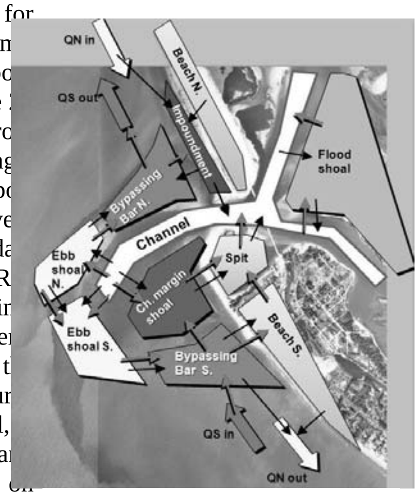

Fig. 6. Longboat Pass IRM setup

IRM Results. The model outputs calculated volumes and sediment transport rates for each of the morphologic features identified in Figure 6. The results provide calculated volumes and rates as function of time for each feature for average, maximum and minimum potential sediment transport rates. IRM predictions were compared to measured volume at times when data were available. The measurements (from bathymetric surveys and aerial photographs) described the variation in volumetric change in response to the change in tidal prism in 1957 and the effects of the 1993 mining of the ebb shoal.

Figure 7 shows IRM predictions for sediment transport rates from north into the inlet channel from 1880 to projected rates at 2040. The rates indicate the increase of sediment transport input to the system as the new inlet opened in 1880 and material was eroding from Anna Maria Island to form the new ebb shoal to the north of the previous inlet shoal. As the ebb shoal was reaching its equilibrium to the tidal prism of the 1950s, transport rates to the inlet were leveling. Following construction of the 1957 jetty, the sediment flow to the inlet was interrupted while the jetty was accumulating material from the littoral drift. As the jetty impoundment was filled to the jetty's capacity, the bypassing was reestablished to the prevailing rates.

Another observation from Figure 7 is the effect of the beach nourishment in 1993. The sand placement resulted in greater rates of sediment transport throughout the nourishment project's lifetime, adding more sand input to the system. The additional sediment transport input to the system coupled with the inlet migrating landward due to the 1993 dredging may have contributed to the observed increase of shoaling areas inside the inlet on the flood shoal and the ICW channel areas.

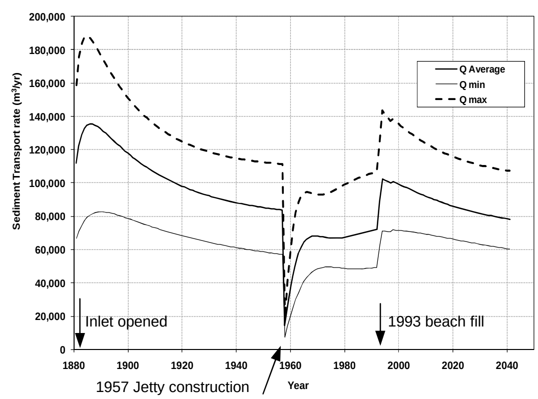

Fig. 7. Transport rates to Longboat Pass

Figure 8 shows IRM predictions for total ebb shoal volume. The figure displays the calculated volume of the ebb delta from 1880 when the older inlet delta existed, present conditions, and projection of future trends. The calculations are in good agreement with measurement from available surveys, including the relatively constant shoal volume for the early period, the increase in ebb shoal volume after construction of the jetty in 1957, and the significant impact on the ebb shoal volume from the 1993 ebb shoal mining and limited recovery.

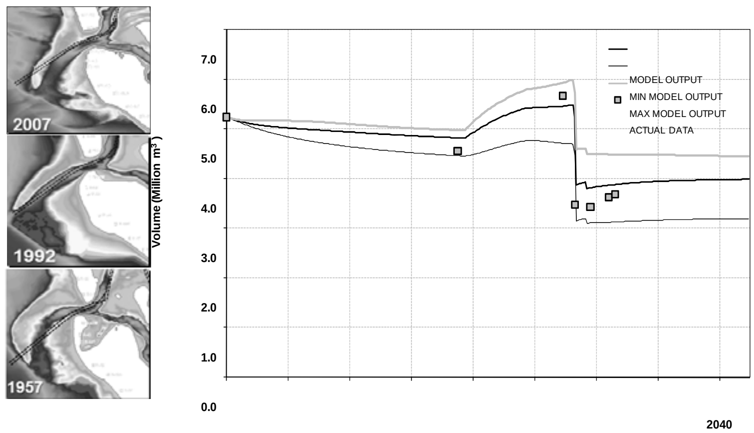

Fig. 8. Calculated and measured ebb shoal volume

IRM projections indicate that little recovery to pre 1993 conditions should be expected in the future as a consequence of the mining of large volume from the ebb shoal. The available data indicate that over a 14-year period, the recovery has been only approximately 10% of the material removed in 1993. This slow recovery rate supports the conclusion drawn from IRM calculations, that the inlet bypass process has been modified by the dredging in such a way that significant recovery is unlikely to occur in the near future.

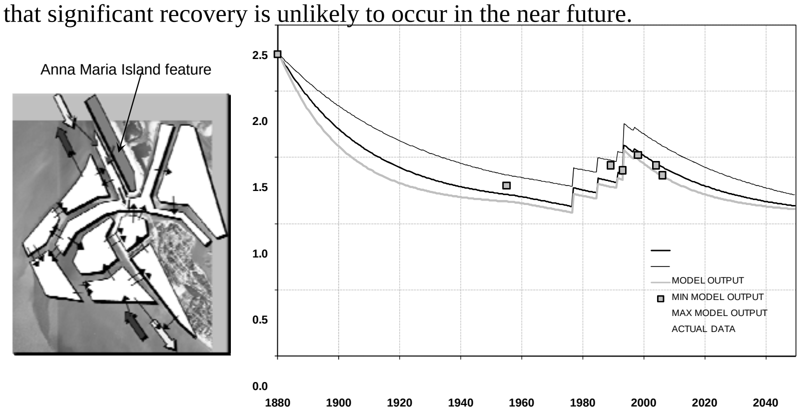

Fig. 9. Calculated and measured volume of Anna Maria Island

Figures 9 and 10 show the model results for beaches adjacent to inlet, Anna Maria Island at the north and the sand spit at the south side of the inlet respectively. Figure 9 plots the initial erosion of Anna Maria Island beach as the ebb shoal was forming. The results also contain the effect of the beach fill from the dredging disposal and large nourishment project in 1993. Similarly, Figure

10 shows the model calculations and predications for sand spit at Longboat Key. IRM calculations are in agreement with measurement from available surveys. The model results also indicate the growth of the sand spit and the effect of the 1993 on the erosion of the spit.

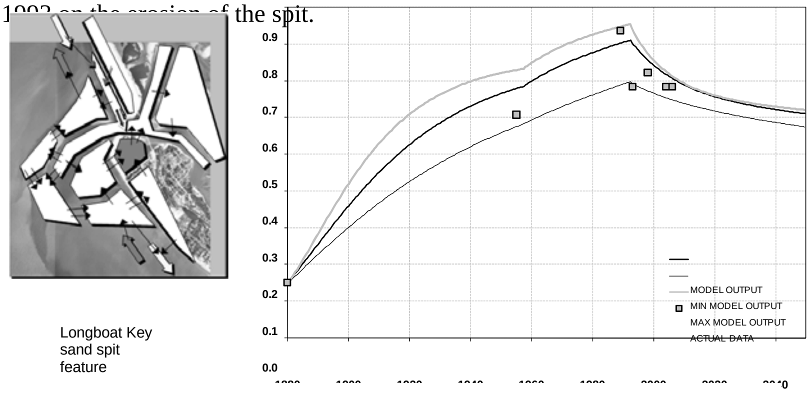

Fig. 10. Calculated and measured volume of the sand spit of Longboat Key

CONCLUDING DISCUSSION

The purpose of this study was to understand consequences of past management and improve future management of Longboat Pass. The evaluation included dredged sand from channel maintenance for mitigation of inlet impacts to adjacent beaches, as well as mining sand from other parts of the shoal system as a source of material for nourishment of beaches in areas beyond the influence of the inlet.

There were three primary elements to the modeling – regional hydrodynamics; detailed or local-processes of waves, flow, and sediment transport; and long-term morphology change. The regional model accounted for the interrelated nature of flow through the various bays and inlets and provides water level and tidal current values that served as input for the local process modeling. The local modeling calculated sand transport rates and transport pathways for the IRM, which simulated the morphological evolution of inlet shoals. The IRM was then configured and run to evaluate the consequences of mining sand, as well as the rate at which shoals should be expected to recover after dredging.

Historical aerial photographs and bathymetric data are valuable for supporting such an integrated modeling effort in establishing reliable model grids. Additionally, large-scale morphology change must be considered in the setup of modeling procedures for different time intervals. Since 1880 when Longboat Pass opened, two major events changed the inlet's dynamics and produced significant morphological responses: construction of the north jetty in

1957, and the 1993 dredging of over 2 million cubic yards from the ebb shoal for beach nourishment.

Opening of the inlet in 1880 north of the previous inlet location resulted in erosion of the south end of Anna Maria Island to form the new ebb shoal, and the onshore migration of the original ebb shoal caused accretion south of the inlet and formation of the sand spit at the north end of Longboat Key that became known as Beer Can Island. Jetty construction and improvements of navigation waterways in the 1950s increased tidal prism and growth of the ebb shoal. The increased capacity for sand deposition in the jetty impoundment and ebb shoal interrupted natural bypassing to the downdrift side of the inlet in the 1960s. In response, the north part of Longboat Key and the Beer Can Island spit breached near the location of the old inlet. Sand bypassing was gradually reestablished, and the Beer Can Island spit reattached to Longboat Key by 1970.

Maintenance dredging of the federal channel, which began in 1977, limited the growth of the ebb shoal with the volume apparently stabilized slightly under its equilibrium potential. Dredging was relatively infrequent with an interval between dredging events of typically more than 5 years, and the volume dredged was relatively small. The large-scale dredging of over 1.5 million cubic meters from the ebb shoal in 1993 interrupted the natural balance between sand transport induced by wave-induced and tidal circulation. Immediately following this dredging, the shoal features were dominated by waves, causing severe erosion of the downdrift shoals and beach. The erosion of the sand spit occurred as the channel migrated to the south.

Analysis of historic changes, available data, and modeling of coastal processes indicate minor recovery in total ebb shoal volume has occurred. However, because of the altered channel orientation and position closer to shore, the authorized federal channel no longer follows the natural tidal channel. This has reduced scouring action in the navigation channel by the tidal current.

The combination of the CMS wave, flow, and sediment transport process modeling with the simple long-term morphology of the IRM provides a practical methodology to evaluate long-term inlet evolution and to evaluate alternatives for improving management of tidal inlets. Through this case study, the paper presents a general methodology for simulating the evolution of different morphologic features and assessing the cumulative consequences of dredging. Time scales of shoal recovery and consequences of interruption of natural sand bypassing can therefore be quantified.

ACKNOWLEDGMENTS

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